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Predicting Ranger Assessment and Selection Program 1 success and optimizing class composition

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MONTEREY, CALIFORNIA

THESIS

PREDICTING RANGER ASSESSMENT AND SELECTION PROGRAM 1 SUCCESS AND OPTIMIZING CLASS COMPOSITION

by

Anthony D. Smith

June 2017

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13. ABSTRACT

The 75th Ranger Regiment is a US Army Special Operations unit responsible for executing raids and forcible entry missions across the globe within 18 hours of notification. In this thesis, we conduct the first data analysis and optimization of Ranger Assessment and Selection Program 1 (RASP1). RASP1 is an eight-week selection for volunteers in the grade of E1 (Private) to E5 (Sergeant) implemented up to ten times per year. We create logistic regression and partition tree models to identify significant factors that contribute to a candidate's success at RASP1 and predict graduation rates. We use an integer linear program (ILP) to prescribe the number of soldiers by grade and Military Occupational Specialty to bring to each RASP1 class to efficiently fill required billets across all units in the Ranger Regiment. We provide the Ranger Regiment leadership with flexible models that offer insight to support their manning decisions. We show effects on RASP1 class composition with changes to capacity constraints, input parameters, and demand. For example, we find the Ranger Regiment could reduce the number of annual RASP1 classes from ten to eight based on several realistic assumptions. Such an annual reduction could save hundreds of man hours and significantly reduce training resource requirements (e.g., ammunition, land use, barracks and food). We encourage detailed exploration of our underlying assumptions and continued use of the ILP.

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PREDICTING RANGER ASSESSMENT AND SELECTION PROGRAM 1 SUCCESS AND OPTIMIZING CLASS COMPOSITION

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ABSTRACT

The 75th Ranger Regiment is a U.S. Army Special Operations unit responsible for executing raids and forcible entry missions across the globe within 18 hours of notification. In this thesis, we conduct the first data analysis and optimization of Ranger Assessment and Selection Program 1 (RASP1). RASP1 is an eight-week selection for volunteers in the grade of E1 (Private) to E5 (Sergeant) implemented up to ten times per year. We create logistic regression and partition tree models to identify significant factors that contribute to a candidate's success at RASP1 and predict graduation rates. We use an integer linear program (ILP) to prescribe the number of soldiers by grade and Military Occupational Specialty to bring to each RASP1 class to efficiently fill required billets across all units in the Ranger Regiment. We provide the Ranger Regiment leadership with flexible models that offer insight to support their manning decisions. We show effects on RASP1 class composition with changes to capacity constraints, input parameters, and demand. For example, we find the Ranger Regiment could reduce the number of annual RASP1 classes from ten to eight based on several realistic assumptions. Such an annual reduction could save hundreds of man hours and significantly reduce training resource requirements (e.g., ammunition, land use, barracks and food). We encourage detailed exploration of our underlying assumptions and continued use of the ILP.

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LIST OF ACRONYMS AND ABBREVIATIONS

ATRRS	Army Training Requirements and Resources System
FY	Fiscal Year
GAMS	Generalized Algebraic Modeling System
GT	General Technical
ILP	integer linear program
MOS	Military Occupational Specialty
MTOE	Modified Table of Organization and Equipment
NATO	North Atlantic Treaty Organization
NCO	Non–Commissioned Officer
NCOIC	Non–Commissioned Officer in Charge
POV	Privately Owned Vehicle
RANGr	RASP1 Accessions Number Generator
RASP1	Ranger Assessment and Selection Program 1
RHQ	Regiment Headquarters
ROC	Receiver Operating Characteristics
RSTB	Ranger Special Troops Battalion
RSTC	Ranger Selection and Training Company
RTB	Ranger Training Brigade
SFAS	Special Forces Assessment and Selection
SOF	Special Operation Forces
TRADOC	Training and Doctrine Command
USASOC	United States Army Special Operations Command
USSOCOM	United States Special Operations Command

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EXECUTIVE SUMMARY

Special Operations Forces (SOF), manned with some of the most physically and mentally talented humans in the Department of Defense, are the force of choice in today's asymmetric and difficult to define battlefield. To fill these units with the right people, all SOF units have assessment and selection programs. The United States Army's 75^{th} Ranger Regiment runs its own selection program at Fort Benning, GA. Ranger Assessment and Selection Program 1 (RASP1) selects soldiers in grades E1 to E5 to fill the ranks of the Ranger Regiment. This study is the first analysis of historical RASP1 data that identifies factors that contribute to graduating RASP1 and predicts success rates. It also develops and implements an integer linear program (ILP) to prescribe an optimal mix of grade and military occupational specialty (MOS) to start each RASP1 class.

We wrangle the RASP1 data from 16 separate excel workbooks, each with five worksheets, into one comma separated value file with 2,359 observations and 64 factors. With this file, we are able to glean precise graduation rates by rank and MOS. We use these figures as inputs to our ILP, RASP1 Accessions Number Generator (RANGr), and to gain a deeper understanding of the data. We highlight the effect of including the Transition Platoon data has on graduation rates. We calculate recycle rates by MOS, rank and phase and show the negative effect recycling has on graduation rates. We also determine that there is not enough evidence to suggest there is seasonality in the data.

We use a simple logistic regression and partition tree to identify significant factors and help predict success at RASP1. Both models show that rank, GT Score, having a car at RASP1, and enlisting from a state in the southern region help predict success at RASP1. Higher rank (SPC and SGT) increases the probability of graduating from RASP1. Having a car at RASP1 also increases the probability of graduating but is likely coincidental and correlated to other factors (higher rank, age, prior service). Enlisting from a state in the Southern region of the US is negatively associated with the probability of graduating RASP1. GT Score is the only factor currently collected by the Ranger Regiment that may assist in discriminating between candidates prior to their

arrival. We show there is evidence that the higher a candidate's GT Score, the higher the probability he will graduate.

RANGr takes precise estimates of graduation rates using historical RASP1 data and provides optimal solutions to fill demand across the Ranger Regiment. We show that under the current capacity constraints and demand assumptions, it is possible to reduce the number of classes from ten to eight. If reducing the number of classes is not an option, it is possible to reduce the class sizes from 165 to 121 (with the right composition) and still fulfill demand requirements. This reduces the number of candidates by 440 for each fiscal year and could reduce the number of RASP1 cadre required to run the course.

RANGr gives the Ranger Regiment leaders precise numbers of candidates to bring to each RASP1 class. We can easily manipulate parameters to help plan for unit allocation changes or unexpected demand fluctuations. We show optimal solutions for increases to demand as well as decreases in graduation rates. RANGr takes less than ten minutes to run, in most cases, and provides valuable insight to the Ranger Regiment leadership regarding their most precious asset, the young Ranger.

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Most authors thank their families for their love and support while working on a thesis. They thank their spouse and kids for putting up with “long days” and “late nights.” On the contrary, my family and I would like to thank the Army for sending us to the Naval Postgraduate School in beautiful Monterey, CA. I will be forever grateful for the family time this duty afforded us and swear to use the tools gained through this education to continue to pursue the enemies of our country.

Lastly, I would like to thank the Rangers of the 75th Ranger Regiment. They are the reason for this study and inspire me every day to “set the example for others to follow.” Rangers Lead the Way!

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I. INTRODUCTION

A. OVERVIEW

Special Operations Forces (SOF), manned with some of the most physically and mentally talented humans in the Department of Defense, are the force of choice in today's asymmetric and difficult to define battlefield. To fill these units with the right people, all SOF units have assessment and selection programs. The United States Army's 75th Ranger Regiment runs its own selection program at Fort Benning, GA. Ranger Assessment and Selection Program 1 (RASP1) selects soldiers in grades E1 to E5 to fill the ranks of the Ranger Regiment. This research analyzes historical RASP1 soldier input and output data to predict success rates. It also develops and implements an integer linear program (ILP) to prescribe an optimal mix of grade and military occupational specialty (MOS) to start each RASP1 class.

The 75th Ranger Regiment is "the Army's premier Special Operations Raid Force" (75th Ranger Regiment 2016b). The Ranger Regiment is one of the units in the United States Army Special Operations Command (USASOC), which falls under the United States Special Operations Command (USSOCOM). The Ranger Regiment's mission is to "plan and conduct special missions in support of United States policy and objectives" (75th Ranger Regiment 2016b). It conducts "large–scale joint forcible entry operations" as well as "surgical special operations raids throughout the world" (75th Ranger Regiment 2016b). Units within the Ranger Regiment have been continually deployed in support of the global war on terrorism since October 2001. The Ranger Regiment has contributed to the elimination or capture of thousands of enemy combatants throughout the past 15 years, and continues to prosecute the threats most dangerous to the United States and its interests today (Figure 1).

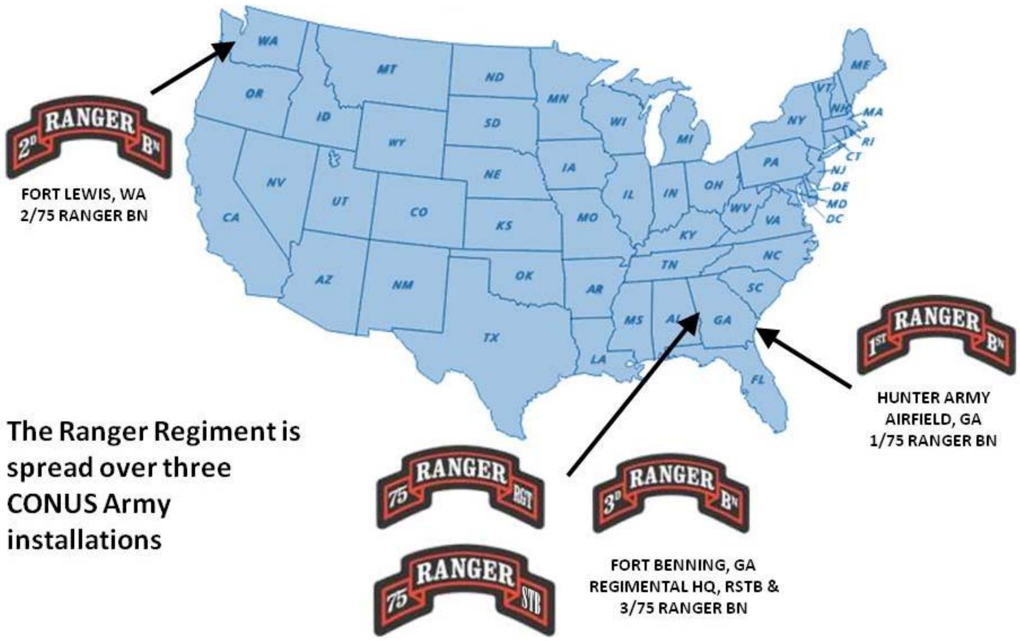
Painting of Ranger Assault Team with Multi–purpose Canine entering a compound in Afghanistan.

Figure 1. “Into the Breach.” Source: Brown (2013).

The Ranger Regiment should not be confused with the Army’s Ranger School, which is a 62–day leadership school that takes place in Georgia and Florida. The Ranger Training Brigade (RTB) runs the course and is part of the Army’s Training and Doctrine Command (TRADOC). The Ranger Regiment sends members of the unit to this leadership school to continue service within the Ranger Regiment, but the two units should not be confused as one and the same. Graduates of Ranger School are said to be Ranger Qualified, but unless they are assigned to the 75th Ranger Regiment, they will return to their sending unit and perform duties associated with that conventional unit’s mission.

There are over 3,000 specially selected soldiers and officers in the Ranger Regiment, spread across four geographically separated Battalions. Within the Ranger Regiment, there are 68 different authorized MOSs ranging from chaplain’s assistant and veterinary technician to infantryman (75th Ranger Regiment 2016b). Ranger Regiment Headquarters (RHQ), 3d Ranger Battalion and the Ranger Special Troops Battalion (RSTB) are located at Fort Benning, GA. 1st Ranger Battalion and 2nd Ranger Battalion

are located at Hunter Army Airfield, GA, and Joint Base Lewis–McChord, WA, respectively (Figure 2).



Geographic locations of all units in the Ranger Regiment

Figure 2. Ranger Regiment Unit Locations. Source: 75th Ranger Regiment (2016b).

The Ranger Regiment runs two Assessment and Selection programs internally year round segregated by rank. The focus of this thesis is on RASP1, which is an eight–week selection for volunteers in the grade of E1 (Private) to E5 (Sergeant). The majority of the volunteers at RASP1 have recently graduated from their initial entry training (Basic and Advanced Individual Training) and Airborne School. There are also in–service volunteers (Prior Service) who come from units spread across the Army's conventional forces. Every candidate must pass the same standards regardless of MOS (i.e., there is not a modified course for cooks or chaplain's assistants). The prerequisites to get orders to RASP1 are to have a General Technical (GT) score of 105, volunteer for airborne school or already be airborne qualified, and be able to obtain a Secret clearance (75th Ranger Regiment 2016b). Additionally, The Ranger Regiment requires leaders to go back and forth between the Ranger Regiment and conventional Army units during their

careers to spread knowledge, skills and abilities throughout the Army and bridge the gap between SOF and conventional units (Odierno 2012).

> The 75th Ranger Regiment remains the most elite infantry force in the world. As the Army's premier special operations raid force with over ten years of continuous combat experience, the Ranger Regiment must carry on its tradition as a standard–bearer for discipline and excellence. It must continue to link our Army's brigade combat teams and special operations forces by migrating its best leaders, training, equipment, and warrior ethos… the 75th Ranger Regiment will stand ready to execute the most difficult joint special operations and forcible entry missions required by our nation. (Odierno 2012)

B. RANGER ASSESSMENT AND SELECTION PROGRAM 1

Currently, the Ranger Selection and Training Company (RSTC) that falls under RSTB at Fort Benning, GA conducts nine or ten RASP1 classes each year with up to 165 candidates starting each class. The Army Training Requirements and Resources System (ATRRS) prescribes the number of candidates per class (150, plus a 10% authorized overage). According to RSTC, the average graduation rate during the last four years is approximately 50% based on rough estimates using crude Excel spreadsheets (Lasseter 2016). This estimate does not factor in candidates who voluntarily withdraw before even starting the course. According to the Ranger Regiment, a candidate must successfully complete the following to graduate RASP1:

- Minimum score of 240 on the Army Physical Fitness Test (80 percent in each event) and ability to complete six chin–ups.
- Must complete five–mile run in 40 minutes or less.
- Must complete 12–mile foot march in three hours or less with a 35lb rucksack.
- Must successfully complete the Ranger Swim Ability Evaluation while displaying confidence in the water.
- Must conduct full psychological screening with no major psychological profiles identified by the Regimental Psychologist.
- Must pass security screening with the ability to be able to receive a SECRET clearance.
- Must pass the Commander’s Board. This event is for select individuals based on peer evaluations, cadre assessment, and overall performance (75th Ranger Regiment 2016a).

A RASP1 class consists of two phases that are each four weeks long. The first phase is primarily focused on physical and mental agility, with several critical events and skill level 1 tasks. Days are stressful, long, and filled with multiple physical events including day and night land navigation. During Phase two, RASP1 instructors focus more on preparing the candidate for service in the Ranger Regiment by teaching the candidates marksmanship, demolition, mobility, and physical fitness (75th Ranger Regiment, 2016a). Upon completion of the assessment, the candidate earns the privilege to wear the tan beret and is assigned to one of the units within the 75th Ranger Regiment (Figure 3).

Figure 3. "Retired Colonel Ralph Puckett places the Ranger Scroll on two graduates of the Ranger Assessment and Selection Program."
Source: 75th Ranger Regiment (2016a)

C. REASON FOR THIS STUDY

> Indeed, the most important component of success in all our missions is the people we commit to them. We are continually seeking new and innovative ways to select the right people, to train them thoroughly, and to develop them professionally throughout their career. All of our major programs for the future start with the premise that we must have the right people in the right place with the right training if we are to succeed. (Downing 1995)

Former commander of USSOCOM and Ranger Regiment, GEN Wayne A. Downing, stressed the importance of selecting the right people to fill the ranks of the special operations units. This is still true today and possibly even more difficult to accomplish based on the complexity of the current threat environment across the globe.

On the basis of the author's first hand knowledge and interviews with personnel officers and Non–Commissioned Officers (NCOs) at RHQ, the current method to calculate the number of candidates to bring into RASP1 every fiscal year is very rudimentary. Currently, RHQ NCOs along with RSTC leadership use an estimate of the aggregate projected losses each year, combined with the estimated graduation rate and the ATRRS class limit, to determine how many candidates are needed each year to fill the required billets. This process could be adjusted to be more efficient and more effective.

There are no known analytic studies of the data obtained during RASP1 to determine what factors contribute to the successful completion of RASP1 or the precise graduation rates by rank and MOS. Historically, the Ranger Regiment has always successfully filled its Infantry coded billets and is currently at 120 percent strength for E1 to E5 infantrymen (Lasseter 2016). Most non–Infantry billets, however, are rarely at or above 100 percent and are always difficult to fill. There is no algorithm to determine how many of each MOS to bring into every RASP1 class to satisfy manning requirements. For example, there was a recent change in the Modified Table of Organization and Equipment (MTOE), which reduced the total number of authorized billets across the Ranger Regiment by 369 (Lasseter 2016). Despite this difference in authorizations, there was no change in the input to each RASP1 class. Also, there is no limit on the number of candidates who can graduate each class. This leads to a potential over–supply of graduates.

The Ranger Regiment's current accessions process for junior enlisted is not completely inoperative. However, because it is moving at the speed of war, there is not always time for the Ranger Regiment to critically analyze every issue. Therefore, the unit may benefit from a more analytical approach of using historical RASP1 soldier input and output data to predict success rates and implement an ILP to prescribe an optimal mix of grade and MOS to start each RASP1 class. In an increasingly restrictive fiscal

environment, this use of data to build an optimization model could prevent over– or under–production. Using this information could potentially save time and money by making best use of personnel and training resources.

D. THESIS SCOPE AND ORGANIZATION

The scope of this thesis includes an analysis of historic RASP1 data and an ILP based on that data analysis. Our analysis of the data identifies significant factors that contribute to a candidate's success at RASP1. We also provide insight into some of the Ranger Regiment's assumptions about RASP1. Our optimization model, RASP1 Accessions Number Generator (RANGr), prescribes the number of soldiers by grade and MOS to bring to each RASP1 class to efficiently fill required billets across all units in the Ranger Regiment. RANGr takes graduation rates from 15 RASP1 classes in Fiscal Year (FY) 15 and FY16 as well as demand figures (projected losses) as inputs to calculate optimal RASP1 class sizes. RANGr uses penalties for failing to fill required billets or over producing Ranger graduates, which allows different inventory management strategies to be evaluated. RANGr gives decision makers at the Ranger Regiment options to adjust their accessions numbers and strategies through optimization techniques.

There are six chapters in this thesis. In Chapter I, we introduce the problem, background information, and the motivation for addressing it. We provide a literature review of similar studies in Chapter II. Chapter III describes the RASP1 data that was collected and analyzed. Chapter IV describes the basis of the ILP and presents the RANGr formulation. We discuss analyses from the data and RANGr in Chapter V. Chapter VI offers conclusions and recommendations for future work pertaining to this study. Lastly, we list the complete description of factors in Appendix A and the base case demand for RANGr in Appendix B.

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II. LITERATURE REVIEW

A. PREVIOUS WORK IN SPECIAL OPERATIONS ASSESSMENTS AND SELECTIONS

Several studies exist that explore assessment and selection programs inside and outside of the military. Researchers discuss a myriad of concepts that are involved in assessing and selecting personnel to perform a specific job within an organization. We focus on military assessments and selections. In particular, we review SOF programs with attributes similar to RASP1. The majority of the unclassified literature revolves around U.S. Army Special Forces Assessment and Selection (SFAS) held at the U.S. Army John F. Kennedy Special Warfare Center and School in Fort Bragg, NC. Despite the significant number of previous studies on these programs, we find no studies that took data from prior selection programs and developed an optimization model to efficiently fill required billets within the gaining unit.

Many of the studies identified or attempted to identify factors that contribute to success (selection or graduation) using various statistical methods. A 1999 Technical Report from the U.S. Army Research Institute for the Behavioral and Social Sciences does an excellent job creating regression models to identify statistically significant factors and predict success for junior enlisted soldiers going through SFAS in the late 1990s. It gives recommendations to recruiters on how to create order of merit lists to identify recruits with the highest potential for success (Zazanis et al. 1999).

North Atlantic Treaty Organization (NATO) authors discuss how various SOF units execute their assessment and selection programs from cradle to grave in order to share best practices across all the NATO countries (Vos and Beezemer 2012). The authors focus again on the attributes (psychological and physiological) of the candidates and the different assessment techniques rather than a scheduling or production style optimization model.

B. PREVIOUS WORK OUTSIDE OF SPECIAL OPERATIONS ASSESSMENTS AND SELECTIONS

There are several articles that discuss scheduling and composition of classes, but most focus on academic schedules at colleges or private schools or assigning students to particular groups. A 2003 dissertation from MIT highlights the positive effect that occurs when mixing cadets at West Point by ability into groups. The authors argue that the proper composition of these social groups is optimal for the efficient production of education at West Point (Lyle 2003).

Daskalaki, Birbas and Housos (2004) along with Drexl and Salewski (1997) discuss school scheduling and different timetabling techniques, which have some similarities to this thesis but are focused on scheduling rather than class compositions. Lieutenant Joseph Scott (2005) built on a 1993 thesis by Kunzman (1993) to look at optimally scheduling instructors at the Defense Language Institute using an integer program. These studies give some insight on scheduling techniques and effects of group composition on success rates, but are not strictly concerned with inventory management techniques.

Brown et al (2001) describe the Kellogg Planning System and its “large–scale, multi–period linear program to guide production and distribution decisions for its food business.” The paper describes the use of a production, inventory, and demand recursion to help Kellogg determine production levels with uncertain demand. This is similar to figuring out how many Rangers need to be “produced” to fill projected losses across the units in the Ranger Regiment. Although the Kellogg Planning System accounts for many more variables than this thesis, the article was helpful in shaping the inventory constraints of RANGr.

Several military officers and scholars have conducted manpower generation and allocation studies dating back to World War II. Some of the more recent works include Workman (2009), Gibson (2007), Yamada (2000), Ginther (2006), and Benson (2008). Workman’s Security Force Generation Model combined both officers and enlisted numbers on a monthly then yearly basis, while the other models were larger and annually based. This thesis differs from these studies because it focuses on the accessions portion

of force management and does not analyze promotion or attrition rates (outside of RASP1). However, we use these studies to generate ideas for our model development and implementation. Another study by Vadja (1978) uses Markov chains within a cohort model to study the growth of units. This is similar to RANGr, where candidates enter RASP1 together, progress through the phases and attrite based on some type of survival function. We use some of the manpower and force management research above to assist in the development of RANGr. We differ from these in using actual historical success rates as inputs to our model.

C. PREVIOUS WORK IN METHODS TO PREDICT SUCCESS

Institutions and organizations across the globe have used various metrics and tests for centuries to assist in determining whether or not an individual will succeed in completing some form of schooling or program. Aptitude tests such as the SAT, ACT, GRE, GMAT all help higher education institutions predict whether or not a potential student has what it takes to complete their program. These metrics give the owners of these programs a method to compare applicants and ensure they are only accepting the right fit for their organization or school. One example of this is a University of California, Berkeley study in 2007 that discussed the validity of High School Records versus Standardized Tests as indicators of Four–Year College Outcomes (Geiser and Santelices 2007). The ability to select the right people for the right programs is good for the organization, individual and society as a whole. There are thousands of similar studies in the education field using different data sets; each argues different factors that contribute to success or failure, but a key purpose of the research is to prevent wasting organizations and individuals’ time and money.

Another interesting field that attempts to identify factors that determine success are multi–trait indices that weigh traits based on their importance to facilitate selection in plant and animal improvement. One study in particular used historical datasets to develop multi–trait selection models in processing tomatoes in California (Liabeuf and Francis 2017). Taking the historical data, they use general linear models with cross–validation to determine which phenotypic traits are significant in predicting success. Knowing which

traits are most significant in making quality tomatoes and increasing yield is similar to finding the traits (test scores or grades) that will help a college assess the likelihood they can turn a high school student into a college graduate. Although these two examples reside in drastically different fields, the underlying desire to use recorded metrics to identify factors that contribute to success or failure is the same.

III. DATA

A. COLLECTION AND CLEANING

The first step in being able to predict success and optimize classes for RASP1 is to gather the necessary data. The Ranger Regiment provided all the data for this thesis, with the majority coming in the form of Excel workbooks from the RSTC. Over the years, Non–Commissioned Officers in Charge (NCOICs) of RASP1 collected the data and their collection techniques varied slightly from class to class. The Excel workbooks are efficient and appropriate for the users, but took a significant amount of wrangling to create factors and put the data into a format that we could analyze with a statistical software program. The three data sets we use are the RASP1 Class Excel workbooks, the Transition Platoon Excel workbook, and the MTOE. We use the R statistical software program for our calculations and model development within this chapter (R Core Team 2016).

1. RASP1 Class Excel Workbooks

The RASP1 NCOICs collected the data we use in this thesis in 15 unpublished Excel workbooks that covered a two–year time period from FY15 and FY16. There are five worksheets in each workbook with data for all the candidates for that particular class. We consolidate this data into one worksheet with 2,359 observations (candidates) and 64 columns. We create a response variable that is binary based on whether a candidate was successful or not in completing RASP1 (1–graduated, 0–failed). The 63 factors include test scores and administrative data that are somewhat sparse because data was only captured for candidates who progressed through the assessment (Appendix A). Of the 63 factors, we focused on 19 that had entries on nearly all 2,359 observations (Table 1). We use this data to analyze graduation rates by MOS and rank, as well as develop prediction models.

Table 1. 19 Factors Analyzed from RASP1 Class Excel Workbooks

Factor	Description
NAME	Generic ID to protect Personally Identifiable Information
MOS	One of 44 Military Occupational Specialties
COMBINED_MOS	One of 17 Military Occupational Specialties
RANK	One of 5 Army Ranks
AGE	Candidate Age in Years at start of RASP1
DOB	Date of Birth M/D/Y
GT_SCORE	General Technical Score 0 to 150
HWI	Binary 1 – Prior Hot Weather Injury, 0 – Not prior HWI
CWI	Binary 1 – Prior Cold Weather Injury, 0 – Not prior CWI
RECYCLE	Binary 1 – Previously Recycled, 0 – Never Recycled
POV	Binary 1 – Has Privately Owned Vehicle at RASP1, 0 – No POV at RASP1
CLASS	RASP1 Class Number FY_ClassNumber
ABN	Binary 1 – Airborne Qualified, 0 – Non Airborne Qualified
MARRIED	Binary 1 – Married, 0 – Not Married
HORState	Service Members Home of Record State
GLASSES	Binary 1 – Wears Glasses, 0 – Does Not Wear Glasses
FINANCE_ISSUES	Binary 1 – Issues with Finance, 0 – No issues with Finance
PRIOR_SERV	Binary 1 – Soldier has Prior Service, 0 – Not Prior Service
Region	One of four Regions for Service Members Home of Record State

During initial investigation of the data, we decided to combine several MOS into their two–number designator parent due to small sample numbers in the data. If there were more than 50 candidates in a specific MOS, we did not combine it with its parent two number designator. The combined MOS categories and the total candidates represented in the RASP1 Class data (excluding the Transition platoon data) are shown in Table 2.

Table 2. Combined MOS Categories

Combined MOS Category	MOSs included (Title)	Total by MOS	Overall Total
11B	11B (Infantryman)	1,524	1,524
11C	11C (Indirect Fire Infantryman)	97	97
12	12B (Combat Engineer)	15	23
	12R (Interior Engineer)	1	
	12W (Carpentry And Masonry)	3	
	12Y (Geospatial Engineer)	4	
13	13F (Fire Support Specialist)	58	58
15	15E (Unmanned Aircraft Systems Repairer)	9	14
	15W (Unmanned Aerial Vehicle Operator)	5	
25	25B (Info System Ops–Analyst)	20	161
	25C (Telecommunications)	24	
	25N (Nodal Network Systems Op/Maint)	32	
	25P (Microwave Systems Op/Maint	7	
	25Q (Multichannel Transmission) Op/Maint)	8	
	25S (Satellite Communication Specialist)	34	
	25U (Signal Supports System Specialist)	32	
	25V (Combat Documentation Specialist)	4	
27	27D (Paralegal Specialist)	10	10
35	35F (Intel Analyst)	44	80
	35G (Imagery Analyst)	15	
	35L (Counterintelligence Agent)	1	
	35M (Human Intelligence Agent)	10	
	35N (Signals Intelligence Analyst)	10	
36	36B (Financial Management Tech)	10	10
42	42A (Human Resources Specialist)	35	35
68	68W (Healthcare Specialist)	149	150
	68X (Mental Health Specialist)	1	
74	74D (Chemical Operations Specialist)	15	15
88	88M (Motor Transport Operator)	27	27
89	89B (Ammunition Specialist)	5	5
91	91B (Wheel Vehicle Mechanic)	17	38
	91C (Utilities Equipment Repair)	1	
	91D (Power–Generation Equipment Repairer)	10	
	91E (Allied Trades Specialist)	2	
	91F (Small Arms/Artillery Repairer)	3	
	91S (Stryker System Maintainer)	5	
92	92A (Automated Logistical Specialist)	13	98
	92F (Petroleum Supply Specialist)	2	
	92G (Food Service Operations)	13	
	92R (Parachute Rigger)	49	
	92W (Water Treatment Specialist)	3	
	92Y (Unit Supply Specialist)	18	
94	94E (Radio and Communications Security)	10	14
	94F (Special Electronic Devices)	4	

Soldiers with the MOS 11B dominate the total number of observations, accounting for 65 percent of the observations (Figure 4). This also highlights how difficult it is for the Ranger Regiment to attract non–Infantry candidates to their demanding selection program.

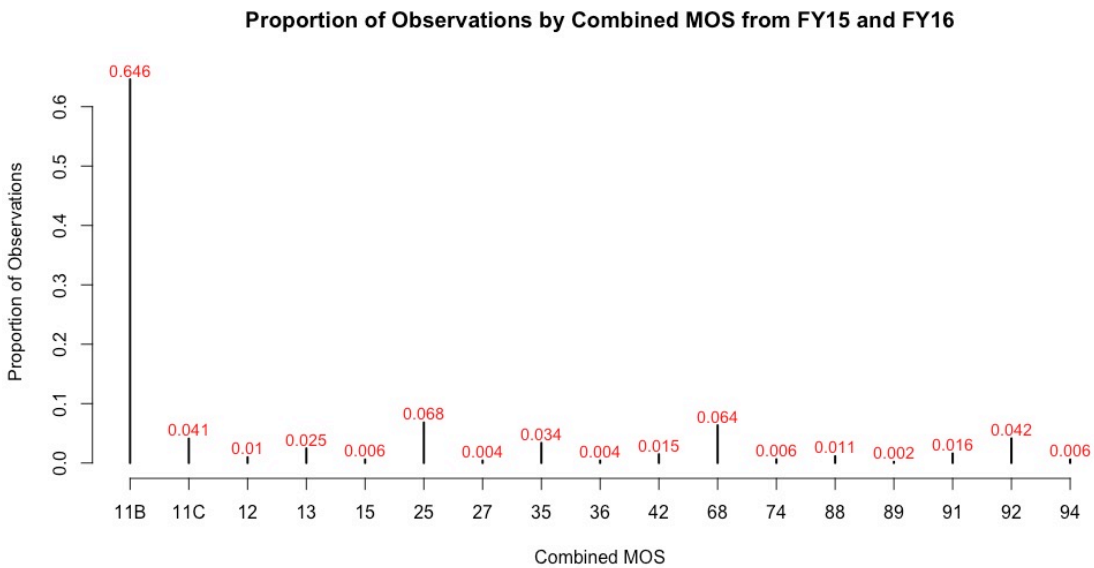

Figure 4. Proportion of Candidate MOSs in FY15 and FY16 RASP1 Classes

2. Transition Platoon Excel Workbook

The Transition Platoon Excel workbook is an unpublished data set that contains data on candidates that are no longer in Pre–RASP or RASP1 (because they did not successfully complete RASP1). These soldiers remain in the same barracks (under different leadership) and depart as soon as they receive orders to go to a conventional Army unit. There are 2,696 candidates in the original data set covering a period from January 2014 through August 2016. We took a slice of this data set and included only the 796 candidates assigned to the transition platoon during the 15 classes during FY15 and FY16 referenced in the RASP1 Excel workbooks above. There are 11 variables in the resulting data set (Table 3). We use this data to supplement the RASP1 Class data to account for graduation rates as a function of arrivals and capacity constraints. Initial

estimates only counted candidates that started a RASP1 class and did not account for the candidates that quit during Pre–RASP.

Table 3. 11 Factors Analyzed from Transition Platoon Excel Workbook

Factor	Description
RANK	Military Rank
MOS	Military Occupational Specialty
ARRIVAL_TO_TransitionPLT	Date Arrived to Transition Platoon
DAYS_ASSIGNED	Total days assigned to Transition Platoon
ABN	Binary 1 – Airborne Qualified, 0 – Not Airborne Qualified
MARRIED	Binary 1 – Married, 0 – not
POV	Binary 1 – Privately Owned Vehicle at RASP1, 0 – no POV
ARRIVED_FROM	Where Candidate came from (PRE–RASP or RASP1)
REASON_DROPPED	Reason Candidate no longer continuing with training
CONTRACT	Type of Contract Candidate had to get orders to RASP1
TODAYS_DATE	Date

B. SUMMARY STATISTICS NEEDED FOR OPTIMIZATION MODEL

We focus our data analysis on gathering necessary input parameters for RANGr. This is the first documented analysis of RASP1 data, so even some of the basic summary statistics provide insights.

1. Effects of Adding Transition Platoon Data to RASP1 Class Data

We aggregate the Transition Platoon data with the RASP1 Class data and concentrate on graduation rates and recycle rates based on MOS and rank. RSTC leadership did not track RASP1 class numbers in the Transition Platoon data, so we divide the candidates evenly across the 15 classes to account for them in our analysis. To get a baseline, we calculate the graduation rates based on only the RASP1 class data without the Transition Platoon data included. When we add the additional Transition

platoon, the graduation rates decrease in all but three MOSs that did not have large enough samples for the rates to be impacted (Figure 5).

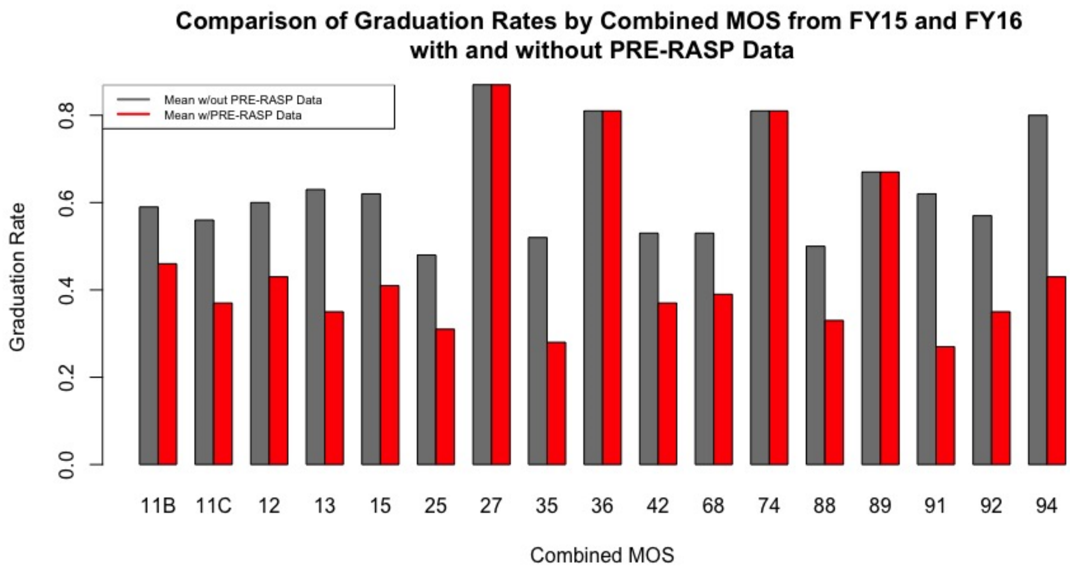

Figure 5. Bar Graph of Graduation Rates by combined MOS Comparing with and without Transition Platoon Data

We add the Transition Platoon data to understand the total number of candidates that are residing in the barracks and how they affect capacity constraints and actual graduation rates. The differences in the graduation rates drastically affect estimates of how many candidates to bring in to each RASP1 class to meet demand. The most significant decreases in graduation rates are the 91 and 94 series MOSs, which are cut nearly in half when we include the candidates who quit prior to starting RASP1. Sample sizes are relatively small for those MOSs, but the impact is important when determining accession numbers.

2. Graduation Rates by Rank and MOS

To get a better estimate of graduation rates, we break down the rates by rank and MOS. The rates are estimates from combining the RASP1 class and Transition Platoon data. Due to small samples for some MOSs, some of the ranks are not represented or

under–represented in the data (e.g., there are no candidates in the rank of PVT and MOS 27). In the instances where a specific rank and MOS does not have an observation (graduation rate = 0) within the data, we use the average of all other MOSs (excluding 11B) within the rank as our estimate. We separate the 11B MOS from the rest of the data because of the drastic difference in sample sizes and overall higher graduation rates. Similarly, some MOS and rank combinations have 100% graduation rates, which are unrealistic and also come from small sample sizes. We use the same method as described above to determine a more accurate figure for our graduation rate parameter. Lastly, if a specific rank and MOS have fewer than 25 observations, we adjust the graduation rate to the average of all other MOSs (excluding 11B) within that rank (denoted by * on Table 4).

Table 4. Graduation Rates by Rank and MOS

MOS	RANK (n)				
	PVT	PV2	PFC	SPC	SGT
11B	0.35 (638)	0.41 (397)	0.55 (253)	0.69 (259)	0.80 (25)
11C	0.38 (40)	0.38 (52)	0.32 *	0.46 *	0.74 *
12, 15, 27, 36, 42, 74, 88, 89, 94	0.19 *	0.26 *	0.32 *	0.46 *	0.74 *
13	0.19 *	0.32 (44)	0.32 *	0.46 *	0.74 *
25	0.19 *	0.28 (138)	0.34 (56)	0.46 *	0.74 *
35	0.19 *	0.21 (52)	0.25 (28)	0.46 *	0.74 *
68	0.19 *	0.31 (96)	0.45 (49)	0.46 *	0.74 *
91	0.19 *	0.12 (52)	0.32 *	0.46 *	0.74 *
92	0.19 *	0.31 (75)	0.32 *	0.46 *	0.74 *

The graduation rates compared to rank for all the MOSs with sample sizes larger than 50 are shown in Figure 6. For most MOSs, as rank increases, so do graduation rates. We expect to see this trend because we assume that a candidate with a higher rank has more maturity and experience in the Army and should be more likely to successfully complete RASP1.

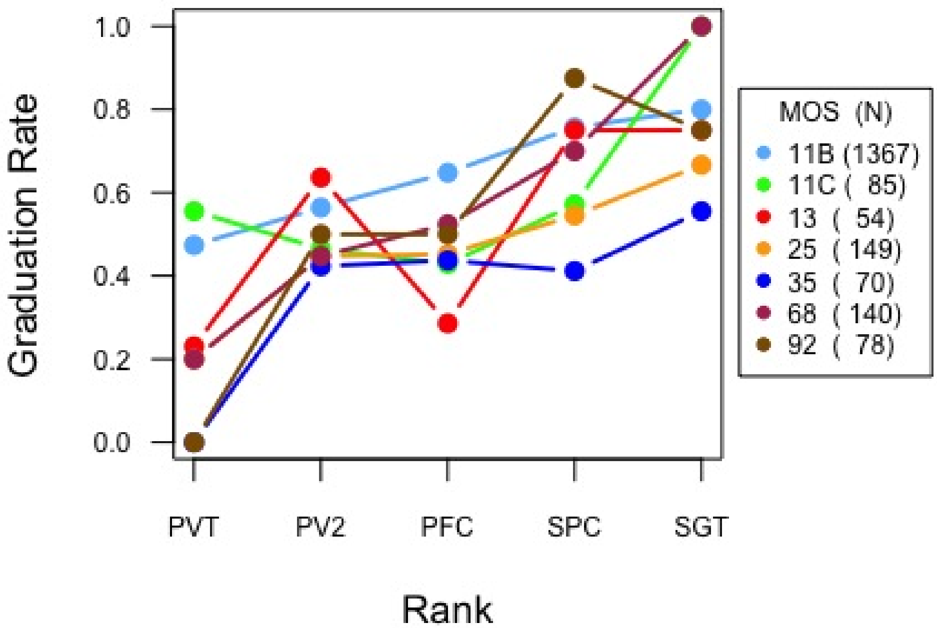

Figure 6. Graduation Rates Compared to Rank for MOSs with 50 or Greater Observations

3. Recycle Rates by Rank and MOS

We calculate the recycle rates by rank and MOS similarly to the non–recycles described above. However, due to the small samples for the majority of the ranks and MOSs, we separate 11Bs from all other MOSs and take the average graduation rate by rank. The recycle graduation rates are significantly lower than those of the candidates that are attempting RASP1 for the first time (Table 5).

Table 5. Graduation Rates for Recycled Candidates

MOS	**RANK (n)**				
	PVT	PV2	PFC	SPC	SGT
11B	0.19(67)	0.35(46)	0.33(21)	0.40(20)	0.67(3)
ALL other MOSs	0.21(14)	0.23 (31)	0.27(15)	0.39(18)	0.6(5)

This shows that in most cases, based on such low graduation rates, the Ranger Regiment should be very judicious on who they allow to recycle. If class capacity is an issue, they may benefit by giving the recycled candidate's slot to someone going through RASP1 for the first time. As highlighted in Figure 7, regardless of rank, candidates that have previously recycled are less likely to graduate based on the FY15 and FY16 averages than those going through RASP1 for the first time.

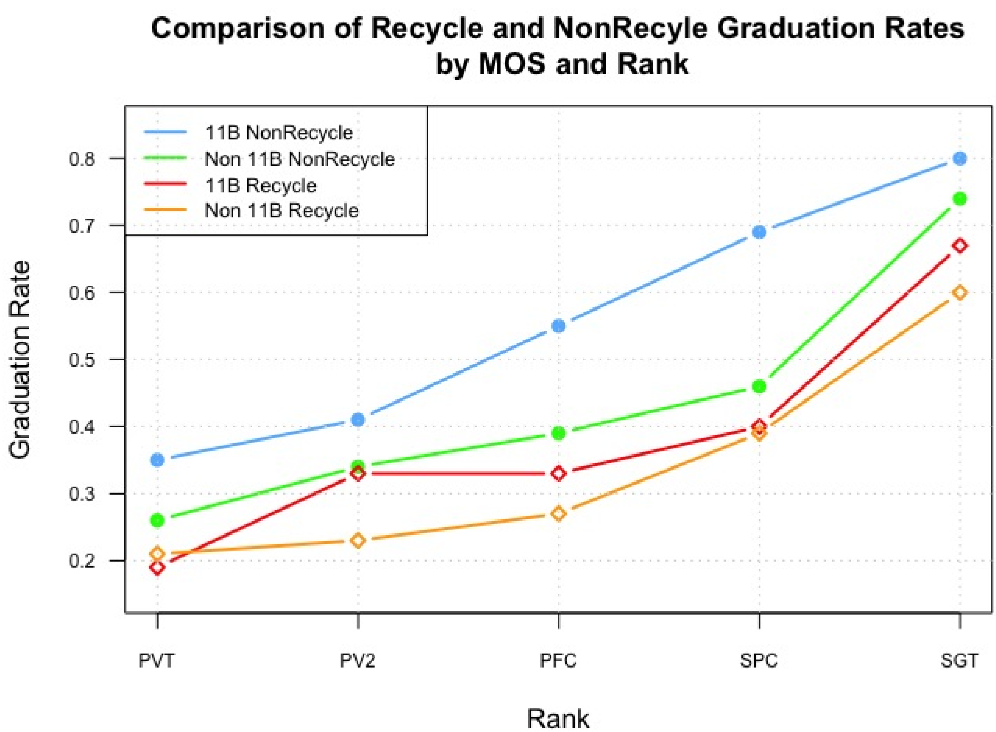

Figure 7. Graduation Rates for 11B and All Other MOSs for Candidates Who have Never Recycled and Those Who have Recycled

4. Recycle Rates by Phase

To determine an expected number of recycles by phase, we use an estimate based on the RASP1 data. This data is not captured directly in the RASP1 data, so we assume if a candidate was recycled and has data entered for events that took place during the second phase, he was recycled in phase 2. Therefore, if there are no data entries for the events that take place in phase 2 and a candidate was recycled, we assume it occurred in

phase 1. There are 234 recycles in the RASP1 class data. By inspection, we deduce that 140 candidates (60 percent) are recycled during the first phase with the remaining 94 candidates (40 percent) recycling in phase 2.

C. OTHER INSIGHTS FROM RASP1 DATA

The following analysis of the RASP1 data is an initial search for significant factors that contribute to success at RASP1. It is intended to provide preliminary insights to the Ranger Regiment leadership and to gain a better understanding of the data. We focus on factors that have entries for nearly all 2,359 observations, which happen to be mostly administrative data that is collected prior to a candidate starting RASP1. After removing some observations for duplicate entries (recycles) and due to missing values, we use a training set with 1,687 observations and a test set with 421 observations (2,108 total). We use a logistic regression model and a partition tree to identify statistically significant factors and to predict whether a candidate will be successful in graduating from RASP1.

1. Logistic Regression

We use a logistic regression with a binary response variable (1 – Candidate Graduated, 0 – Candidate Failed) and 10 variables to identify statistically significant factors (Table 6). We added an additional variable for the time of year the class was held (season) to identify seasonality. We created this factor based on an assumption that graduation rates are lower during summer months. However, we do not use it in the final model because it was not statistically significant at the 0.05 level. We use the *glm* function in the base package of R to produce the logistic regression model.

Table 6. List of Factors Used in Logistic Regression Model

Factor	Description
RANK	One of five Army Ranks
AGE	Candidate Age in Years at start of RASP1
GT_SCORE	General Technical Score 0 to 150
HWI	Binary 1 – Prior Hot Weather Injury, 0 – Not prior HWI
RECYCLE	Binary 1 – Previously Recycled, 0 – Never Recycled
POV	Binary 1 – Has Privately Owned Vehicle at RASP1, 0 – No POV at RASP1
MARRIED	Binary 1 – Married, 0 – Not Married
Region	One of four Regions for Service Member's Home of Record State
GLASSES	Binary 1 – Wears Glasses, 0 – Does Not Wear Glasses
PRIOR_SERV	Binary 1 – Soldier has Prior Service, 0 – No Prior Service

For simplicity, we choose a model that only looks at main effects without any interactions. According to the model, the most statistically significant factors in determining success at RASP1 are POV, RANK, GT_SCORE, Region, and GLASSES (Table 7).

Table 7. Logistic Regression Model Coefficients and P Values

Factor	Coefficient	P Value
Intercept	–0.9684	0.1762
POV	0.4652	0.0002
RANK SPC	0.5301	0.0016
RANK PVT	–0.4508	0.0017
GT_SCORE	0.0132	0.0117
Region South	–0.3130	0.0154
GLASSES	–0.2472	0.0226

a. Logistic Regression Analysis

We use the test set to evaluate the logistic regression model on how well it predicts that a candidate will graduate from RASP1. We display the results using a standard confusion matrix (Figure 8) and a Receiver Operating Characteristics (ROC) Curve (Figure 9). Overall, the model's accuracy is 0.596 (misclassification rate = 0.403).

		Actual Value	
		0	**1**
Predicted Value	**0**	91	69
	1	101	160

Figure 8. Confusion Matrix for Logistic Regression Model

The ROC Curve shows the tradeoff between changing levels of specificity and sensitivity. The farther the curve is from the diagonal line, the better it is at predicting outcomes. The area under the curve is 0.636 for this model.

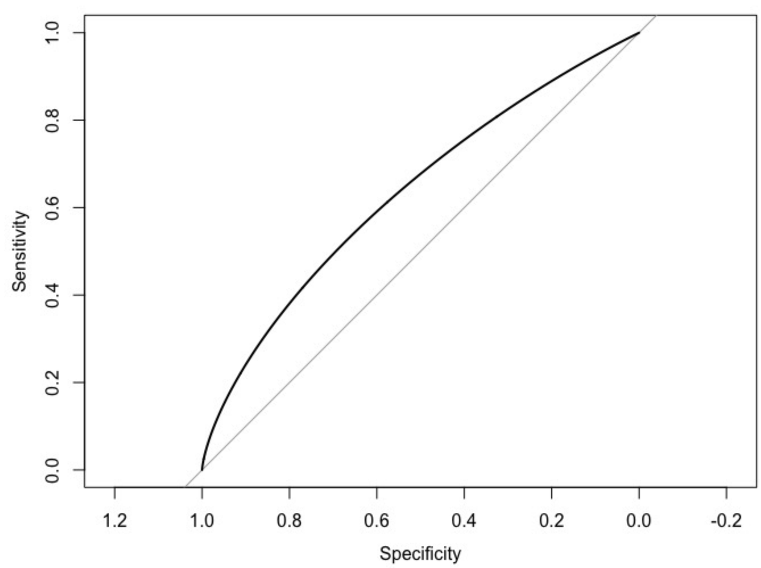

Figure 9. ROC Curve for Logistic Regression Model

2. Partition Tree

We also analyze the data using partition trees to identify significant factors that contribute to success at RASP1. The tree provides a classification tool for the Ranger Regiment to use when determining the likelihood of success for a candidate with specific traits. We use the *rpart* and *rpart.plot* functions in R to create the partition tree using the same factors used in the logistic regression above (Table 6). In order to prevent over fitting, we manually set the complexity parameter based on where the values of the cross–validated relative error begins to increase as the number of nodes increases (Therneau, Atkinson and Ripley 2013). In this tree, we set the complexity parameter to 0.0042.

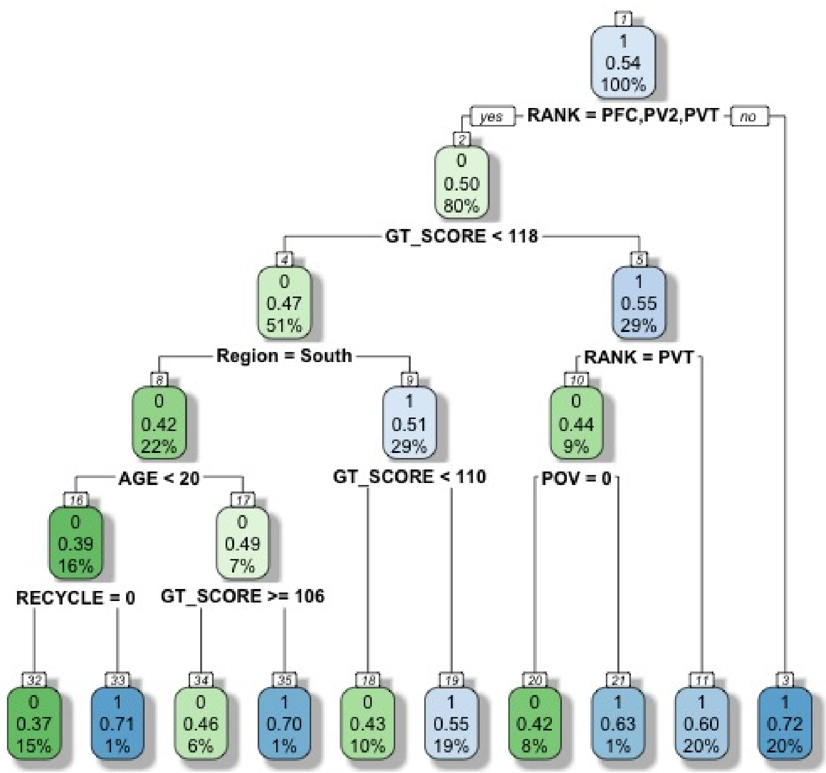

Figure 10. Partition Tree with Binary Response and 10 Factors

This partition tree uses six of the ten factors and splits first on Rank. The nodes are numbered at the top of each node for reference. The tree uses Boolean expressions of

yes or no to determine which direction to split to child nodes (yes to the left and no to the right). The decimal value inside the node is the predicted probability a candidate will graduate from RASP1. The percentage inside the node is the percentage of candidates out of the entire dataset that fall into that node. The darker the node color, the higher the probability. The highest probability in this tree is at node 3. If a candidate is a SPC or SGT, the predicted probability he graduates RASP1 is 0.72 and 20 percent of the observations fall into this node. The lowest probability of 0.37 is at node 32. Candidates in this node are PVTs, PV2s, or PFCs, have a GT score less than 118, are from the South Region, less than 20 years old and have never recycled. 15 percent of the observations are in this node.

Next, we see that the partition tree is split three times by the GT Score variable. This is one of the only factors that the Ranger Regiment can use to discriminate candidates prior to their arrival. A common assumption within the Ranger Regiment is the higher the GT Score, the higher the probability a candidate will graduate RASP1 (Masters 2016). This tree, along with the GT Score distribution graph below, affirms this assumption (Figure 11).

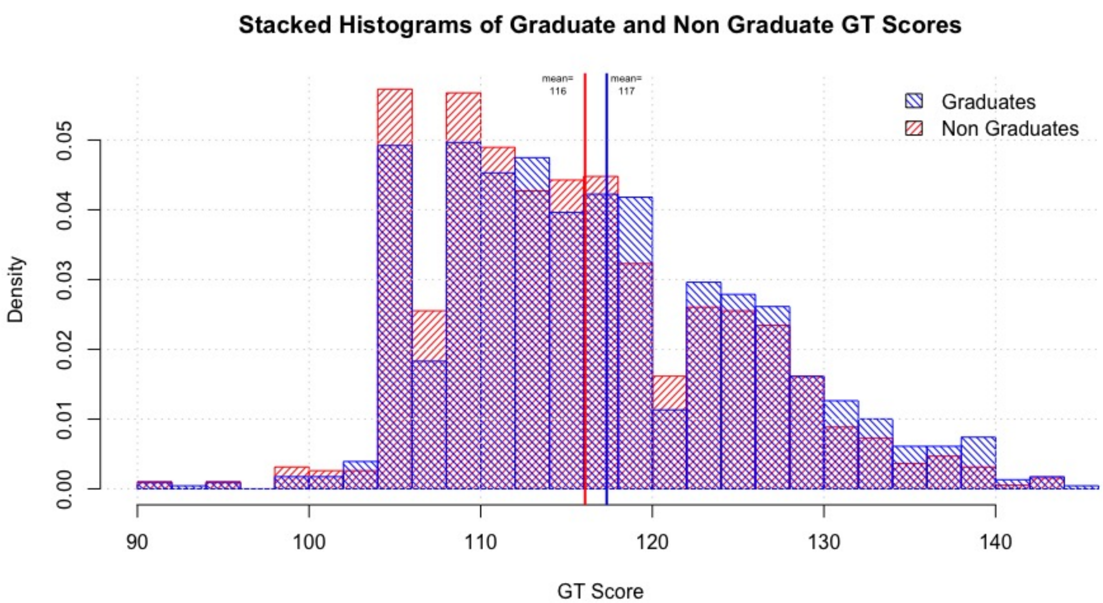

Figure 11. Distribution of GT Scores for Graduates and Non-graduates

The mean GT Score for failures is 116, while the mean GT Score for graduates is 117. If we only look at means, we could argue that a higher GT Score has very little effect on successfully completing RASP1. However, as highlighted in Figure 11, the distribution of higher GT Scores is much more prevalent for the graduates than the failures.

a. Partition Tree Analysis

We use the test set to evaluate the partition tree model on how well it predicts a candidate graduating from RASP1. We display the results using a standard confusion matrix (Figure 12) and a Receiver Operating Characteristics (ROC) Curve (Figure 13). Overall, the model's accuracy is 0.618 (misclassification rate = 0.382).

		Actual Value	
		0	**1**
Predicted Value	**0**	91	60
	1	101	169

Figure 12. Confusion Matrix for Partition Tree Model

The partition tree model is slightly more accurate than the logistic regression model, but only in finding the true positives. The ROC Curve shows similar results as the logistic regression model, but the area under the curve is only 0.604.

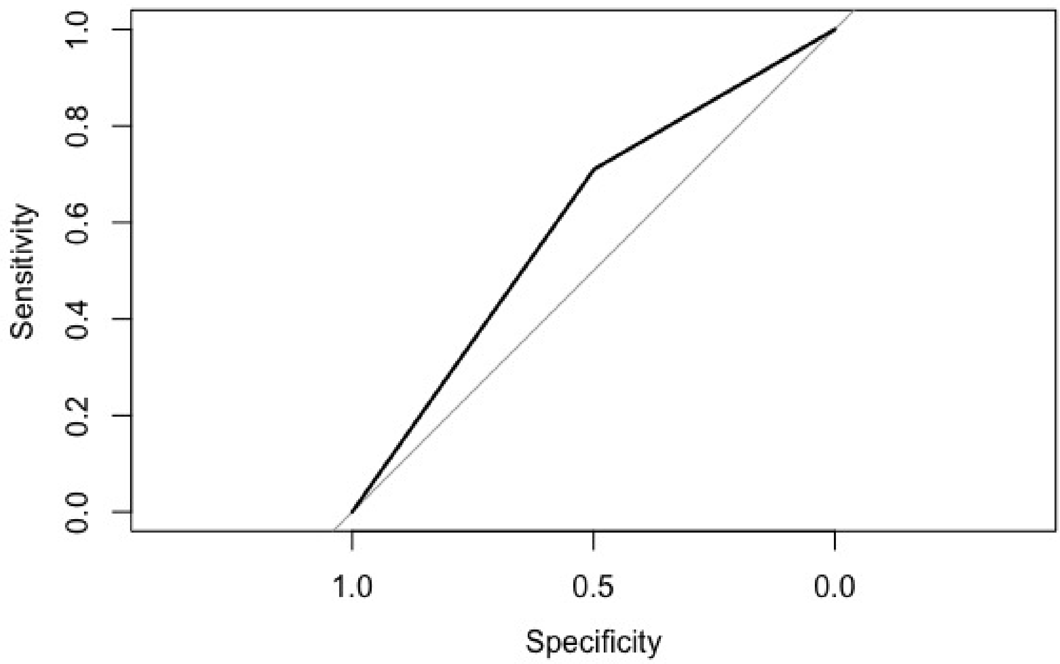

Figure 13. ROC Curve for Partition Tree Model

D. DATA SUMMARY

After significant wrangling of the RASP1 Data and Transition Platoon Data, we are able to glean precise graduation rates by rank and MOS. We use these figures as inputs to RANGr and to gain a deeper understanding of the data. We highlight the effect including the Transition Platoon data has on graduation rates. We calculate recycle rates by MOS, rank and phase and identify the effect recycling has on graduation rates. We also use two models to identify significant factors that contribute to a candidate graduating RASP1. Four of the six significant factors are the same in both models (RANK, GT_SCORE, POV, Region South) with RECYCLEs and AGE showing up only in the partition tree and GLASSES appearing significant only in the logistic regression model. We determine that there is not enough evidence to say there is seasonality in the data. Lastly, we affirm the Ranger Regiment's assumption that higher GT scores contribute to higher probability of graduating RASP1.

IV. MODEL DEVELOPMENT

In this chapter, we describe RANGr, provide information on the assumptions, and present the ILP formulation.

A. RASP1 ACCESSIONS NUMBER GENERATOR

1. Assumptions

1. RANGr assumes that RASP1 classes are eight weeks in length, split into two equal phases.

2. We use a piecewise linear function with two break points with increasing slopes that adds a cost to the backlog for not filling demand.

2. Model Formulation

This section presents the indices, parameters, decision variables, objective function, and constraints that comprise the mathematical formulation of RANGr (Brown and Dell 2007).

a. Indices [Cardinality]

i	Piecewise Linear Interval [3]
m	Military Occupational Specialty (MOS) [17]
r	Military Rank [3]
c	RASP1 Class [10/Year]
b	Ranger Battalion/Unit [3]

b. Data [Units]

1. Initial Conditions

$sinv_{mr}$	Pool of MOS *m*, rank *r* graduates available for assignment at start [Graduates]
$sph2_{mr}$	Pool of MOS *m*, rank *r* candidates in Phase 2 of training at start [Candidates]

2. Ranger Production

d_{mrcb}	New demand for MOS *m*, rank *r*, for graduation class *c*, at battalion *b* [Candidates]
$\overline{class}_c$	Upper limit on number of candidates allocated to start each class as prescribed by Army Training Requirements and Resources System (ATRRS) [Candidates]
$rate_{mr}$	Graduation rates for MOS *m*, rank *r* that have never recycled [$\frac{\text{Graduates}}{\text{Candidates}}$]
$rrate_{mr}$	Graduation rates for MOS *m*, rank *r* that have previously recycled [$\frac{\text{Graduates that previously Recycled}}{\text{Candidates}}$]
$ph1rec_{mr}$	Fraction of MOS *m*, rank *r*, candidates that recycle during phase 1 and can enter following class *c+1* [$\frac{\text{Candidates Recycled in PH1}}{\text{Candidates}}$]
$ph2rec_{mr}$	Fraction of MOS *m*, rank *r*, candidates that recycle during phase 2 and cannot enter again until class *c+2* [$\frac{\text{Candidates Recycled in PH2}}{\text{Candidates}}$]
$mfill_{mrb}$	Maximum fill rate of MOS *m*, rank *r*, for battalion *b* [$\frac{\text{Graduates}}{\text{Candidates}}$]
$\overline{unmet}_{imrc}$	Upper limit on number of unmet demand by index *i*, MOS *m*, rank *r*, for each class *c*

3. Barracks Space/Capacity

$rec1_{mr}$	Number of MOS *m*, rank *r*, candidates recycled and waiting to start at beginning of Class 1 [Candidates]
$rec2_{mr}$	Number of MOS *m*, rank *r*, candidates recycled and waiting to start at beginning of Class 2 [Candidates]
$\overline{newup}_{mrc}, \underline{newlo}_{mrc}$	Upper and Lower goal on total MOS *m*, rank *r*, for class *c* [Candidates]
$\overline{beds}_c$	Upper limit on total at RASP1 for class c (based on available barracks space) [Candidates]
$SA4_{mr}$	Fraction of MOS m, rank r, candidates that survive after four weeks and advance to Phase 2 [$\frac{\text{Candidates advancing to PH2}}{\text{Candidates}}$]

4. Penalties

$pback_{imrc}$ Penalty for index i, MOS m, rank r billet going unfilled (Backlog) after class c [10]

$pover_{mrc}$ Penalty for MOS m, rank r, class c for overfilling billets [1]

c. Integer Variable

X_{mrc} Integer number of MOS m, rank r candidates to start class c

d. Positive Variables

I_{mrc} Number of MOS m, rank r graduates from class c (Inventory)

B_{imrc} Number of MOS m, rank r billets waiting to be filled after class c at index i

e. Formulation

$$Min \quad \sum_{imrc} pback_{imrc} B_{imrc} + \sum_{mrc} pover_{mrc} I_{mrc} \tag{0}$$

f. Constraints

$$\sum_{mr} X_{mrc} + \sum_{mr} rec1_{mr} \le \overline{class}_c \qquad c = 1 \tag{1}$$

$$\sum_{mr} X_{mrc} + \sum_{mr} ph1rec_{mr} X_{mrc-1} + \sum_{mr} rec2_{mr} \le \overline{class}_c \qquad c = 2 \tag{2}$$

$$\sum_{mr} X_{mrc} + \sum_{mr} ph1rec_{mr} X_{mrc-1} + \sum_{mr} ph2rec_{mr} X_{mrc-2} \le \overline{class}_c \qquad c > 2 \tag{3}$$

$$\sum_{mr} X_{mrc} + \sum_{mr} rec1_{mr} + \sum_{mr} sph2_{mr} \le \overline{beds}_c \qquad c = 1 \tag{4}$$

$$\sum_{mr} X_{mrc} + \sum_{mr} (SA4_{mr} * (X_{mrc-1} + rec1_{mr})) \le \overline{beds}_c \qquad c = 2 \tag{5}$$

$$\sum_{mr} X_{mrc} + \sum_{mr} (SA4_{mr} * (X_{mrc-1} + ph1rec_{mrc-2} X_{mrc-2} + rec2_{mr})) \le \overline{beds}_c \qquad c = 3 \qquad (6)$$

$$\sum_{mr} X_{mrc} + \sum_{mr} (SA4_{mr} * (\sum_{mr} X_{mrc-1} + ph1rec_{mrc} X_{mrc-2} + \sum_{mr} ph2rec_{mrc} X_{mrc-3})) \le \overline{beds}_c \qquad c > 3 \qquad (7)$$

$$I_{mrc} - \sum_{i} B_{imrc} = sinv_{mr} - \sum_{b} d_{mrcb} + rate_{mr} X_{mrc} + rrate_{mr} rec1_{mr} \qquad \forall\ m, r, c = 1 \qquad (8)$$

$$I_{mrc} - \sum_{i} B_{imrc} = I_{mrc-1} - \sum_{b} d_{mrcb} - B_{imrc-1} + rate_{mr} X_{mrc} + rrate_{mr} (ph1rec_{mrc-1} X_{mrc-1} + rec2_{mr}) \qquad \forall\ m, r, c = 2 \qquad (9)$$

$$I_{mrc} - \sum_{i} B_{imrc} = I_{mrc-1} - \sum_{b} d_{mrcb} - B_{imrc-1} + rate_{mr} X_{mrc} + rrate_{mr} (ph1rec_{mrc-1} X_{mrc-1} + ph2rec_{mrc-2} X_{mrc-2}) \qquad \forall\ m, r, c > 2 \qquad (10)$$

$$\sum_{i} B_{imrc} \le \sum_{b;\, c' \le c} d_{mrc'b} \qquad \forall\ m, r, c \qquad (11)$$

$$B_{imrc} \le \overline{unmet}_{imrc} \qquad \forall\ i, m, r, c \qquad (12)$$

$$I_{mrc} \le \sum_{b} mfill_{mrb} \sum_{c'b} d_{mrc'b} \qquad \forall\ m, r, c \qquad (13)$$

$$\sum_{r \in \{E5\}} \sum_{m} X_{mrc} \ge 1 \qquad \forall\ c \qquad (14)$$

$$\underline{newlo}_{mrc} \le X_{mrc} \le \overline{newup}_{mrc} \qquad \forall\ m, r, c \qquad (15)$$

$$X_{mrc} \ge 0 \text{ and integer} \qquad \forall\ m, r, c \qquad (16)$$

$$I_{mrc} \geq 0 \qquad \forall\ m,r,c \qquad (17)$$

$$B_{imrc} \geq 0 \qquad \forall\ i,m,r,c \qquad (18)$$

3. Explanation of Model Formulation

Equation (0) is RANGr's objective function. It has piecewise linear functions that penalizes for under producing graduates and also penalizes for over producing. It has two components:

(a) $\sum_{imrc} pback_{imrc} B_{imrc}$

(b) $\sum_{mrc} pover_{mrc} I_{mrc}$

The first component of the objective function expresses the cost of not filling a demand for each MOS, rank and class. It includes a piecewise linear function index that models increasing cost as the backlog increases. The second component (b) expresses the cost of having inventory for each MOS, rank and class.

Constraint sets (1) through (7) are capacity constraints to account for limited seats in each class as well as barracks space. Due to classes overlapping, there are different constraints for up to the third class. The first three are upper limits on the number of candidates that can start a class based on the ATRRS imposed ceiling of 165 candidates. Constraints (4) through (7) are upper limits on barracks space to accommodate the total number of candidates in a class, waiting to start the next class or in the Transition Platoon awaiting orders to a conventional Army unit.

Constraint sets (8) through (13) are inventory management constraints to account for the production of Graduates by grade and MOS at RASP1 based on the demand for each grade and MOS at each unit. Constraint set (11) limits the backlog of graduates by grade and MOS to less than the total demand for each grade and MOS at each unit. Constraint set (12) limits the backlog by index, grade, and MOS for each class be less

than the upper limit of unmet demand for each index, grade, and MOS. (13) limits the number of graduates produced by grade and MOS during each class be less than the maximum fill rate by grade and MOS at each unit.

We address the composition requirements for each class based on grade and MOS with constraint sets (14) and (15). Constraint (14) establishes that at least one candidate hold the grade of E5 for each class. Constraint (15) requires that the number of incoming candidates by grade and MOS for each class is greater than the lower goal and less than the upper goal of candidates for each grade and MOS per class.

Lastly, constraint set (16) indicates a nonnegative integer variable and constraint set (17) and (18) declares positive decision variables.

V. RANGr IMPLEMENTATION AND ANALYSIS

This chapter provides a description of the computer implementation of RANGr, the data, and analysis of sample results.

A. COMPUTER IMPLEMENTATION

We use the optimization software package Generalized Algebraic Modeling System (GAMS), version 24.8.5, to generate RANGr and CPLEX 12.6 to solve it (GAMS 2016). We solve all scenarios of RANGr using a DELL Computer with a 2.70 GHz processor and 128 GB RAM. There are 534 rows and 1280 columns in the reduced ILP. It takes approximately ten minutes to find a solution within 2 percent of optimal. In the base scenario, we use the parameters currently implemented by the Ranger Regiment (Table 8).

Table 8. Base Scenario Parameters for RANGr

Base Scenario			
Number of Classes	**Class Length (weeks)**	**Class Capacity**	**Barracks Capacity**
10	8	165	300

B. DATA IMPLEMENTATION

We use the data discussed in Chapter three as primary inputs to RANGr. We break down the parameters into Starting Conditions, Ranger Production, Barracks Capacity, and Penalties. Additionally, because the RASP1 classes overlap slightly throughout the year, we describe how this affects capacity constraints for the first three classes.

1. Starting Conditions

We start RANGr by assuming there are already candidates in the training pipeline from previous classes (that is, we implemented a warm start). Figure 14 describes how

the 8–week classes overlap and how we account for the candidates already in the pipeline. A candidate can get recycled during phase one or phase two of RASP1. If a candidate recycles during either phase, we assume he will restart training in the next available class.

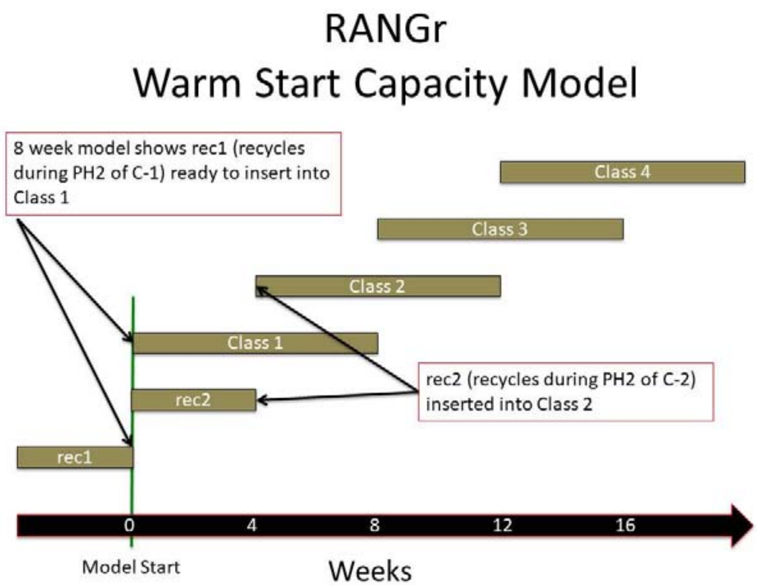

Figure 14. RASP1 Class overlap (Warm Start Capacity Model)

Starting inventory and candidates in phase two of a previous RASP1 class are the two starting condition parameters (Table 9). Due to the size of the files, some of the values of the RANGr parameters are in Appendix B.

Table 9. Starting Condition Parameters for RANGr

Parameter	Value	Explanation
$sinv_{mr}$	0	We assume there are no available graduates to fill demand at the start of the model in this thesis
$sph2_{mr}$	64 (total)	Number of candidates in phase two of previous RASP1 Class

2. Ranger Production Parameters

The next set of parameters is the Ranger production parameters. We use these parameters within the inventory management constraints to account for graduates (Inventory) and unfilled demand (Backlog). We describe them in Table 10.

Table 10. Ranger Production Parameters for RANGr

Parameter	Value	Explanation
d_{mrcb}	Appendix B	Demand
$\overline{class}_c$	165	Maximum number of candidates allowed to start each class
$rate_{mr}$	Table 4	Graduation Rate for non Recycles
$rrate_{mr}$	Table 5	Graduation Rate for Candidates previously recycled
$ph1rec_{mr}$	60%	Fraction of Recycles that recycle during phase 1
$ph2rec_{mr}$	40%	Fraction of Recycles that recycle during phase 2
$mfill_{mrb}$	110%	Maximum fill by MOS, grade per class at each unit

a. Use of MTOE to generate demand

We pulled the MTOE data from Force Management System Web Site to develop estimated demand (U.S. Army Force Management Support Agency 2017). The authorized numbers of personnel and equipment for every TOE unit in the Army is included in this data set. We use the specific MTOEs for the RHQ, RSTB, and each numbered battalion in the Ranger Regiment. We combine all three numbered battalions because all three are identical and we assume that each battalion shares similar demand (Appendix B).

We use the authorized numbers of Rangers by MOS and grade in this data set for the demand parameters in RANGr. Based on personal interviews with the Ranger Regiment Personnel NCOIC and career counselor, we assume that roughly 33 percent of the authorized E1 to E5 billets need to be filled each year due to various forms of attrition (e.g., end of service term, relieved for standards, promotions, etc.) (Lasseter 2016). We

assume that every MOS and grade has the same average attrition rate of 33 percent. MTOEs combine the ranks of PVT, PV2 and PFC as one grade, E3. We combine the MOSs the same way we combine them as described in Table 2. We divide the authorized number by 3 (33 percent attrition) and then by the number of classes per year (ten in the base case) to approximate the demand for a specific grade and MOS for each RASP1 class.

3. Barracks Space Parameters

The next set of parameters is the Barracks Space parameters. We use these parameters with the inventory management constraints to account for all soldiers currently in RSTC taking up barracks space (waiting for RASP1 class, currently in RASP1 class, or currently in Transition Platoon). We describe them in Table 11.

Table 11. Barracks Space Parameters for RANGr

Parameter	Value	Explanation
$rec1_{mr}$	7 (total)	Recycled Candidates waiting to start Class 1
$rec2_{mr}$	3 (total)	Recycled Candidates waiting to start Class 2
$\overline{newup}_{mrc}, \underline{newlo}_{mrc}$	0, 60	Upper and lower goal on number of candidates to start each class
$\overline{beds}_c$	300	Maximum number of candidates on site
$SA4_{mr}$	$1.05 * rate_{mr}$	Fraction of candidates that advance to phase 2

4. Penalty Parameters

We explain the penalty parameters in Table 12. The penalty for not meeting demand is more severe than creating inventory (graduates in excess of demand) because we would rather have inventory than an unfilled billet (i.e., we would rather have an extra rifleman than be short one).

Table 12. Penalty Parameters for RANGr

Parameter	Value	Explanation
$pback_{imrc}$	10	Penalty for not meeting demand
$pover_{mrc}$	1	Penalty for having inventory

5. Objective Function

We focus the objective function of RANGr on the efficient production of graduates. We want to produce the right number of graduates by grade and MOS to fill the demands at each of the units within the Ranger Regiment. There are penalties for not filling required billets (demand) at the end of each class (backlog). There are also penalties for having inventory at the end of each class. We use a piecewise linear function on the backlog penalty that increases as backlog increases to encourage filling the demands.

6. Constraints

We apply constraints in RANGr that limit class sizes and overall number of soldiers at RSTC. Inventory management constraints ensure that demand be filled and not overfilled. We also include a soft constraint of requiring at least one NCO start every class based on recommendations from RSTC leadership (Masters 2016).

C. ANALYSIS

We analyze outputs from RANGr by looking at a base case plus three different scenarios. In the base case, we run RANGr with the Ranger Regiment’s current constraints and assumptions. We change input and demand parameters in the other scenarios to provide insight to Ranger Regiment decision makers. Changing parameters and constraints within RANGr gives the Ranger Regiment options for changing their RASP1 class scheduling and highlights the effects on class composition.

1. Base Case

The Ranger Regiment currently runs nine or ten RASP1 classes per FY. Each class can have up to 165 candidates and the maximum number of soldiers on the ground because of barracks space limitations is 300. We use ten classes for our base case and show that the current capacity constraints are sufficient. The average number of candidates that started a class during FY15 and FY16 is 140. For the ten–class base model, we show that it is possible to fill all demands with as few as 121 candidates starting each class. Therefore, with these demand assumptions and current capacity constraints, the Ranger Regiment could hold as few as eight classes per year and still fill demand up to 110 percent. Running fewer classes each year could save hundreds of man hours and significantly reduce training resource requirements (e.g., ammunition, land use, barracks, and food). Prior to implementing any changes, however, there are several other factors that we do not consider with this model. These factors include arrival times of candidates, increase of soldier idle time, and other scheduling conflicts.

There are significant differences in the model's recommended number of candidates compared to the average number of candidates from the historic data (Table 13). The most significant difference is the average number of 11B candidates that start each class. The optimal solution from the base model shows an average requirement of 61 11Bs across all grades for each class to fill all demand. However, the historic average of 11B candidates that start each class is 90. This surplus of 11B candidates starting RASP1 is one reason the Ranger Regiment is over strength on 11Bs. Anecdotally, a unit rarely complains about being over strength in a particular MOS. This is not the case if a unit is undermanned in any MOS.

Table 13. Disparity in Average Historic RASP1 Class Starting Numbers and RANGr Optimal Solution

MOS	Historic Starting Numbers	RANGr Optimal Solution	Surplus
11B	***90***	***61***	***29***
11C	6	7	–1
12	1	1	0
13	4	5	–1
15	1	1	0
25	10	10	0
27	1	0	1
35	***5***	***9***	***–4***
36	1	1	0
42	2	3	–1
68	9	2	7
74	1	2	–1
88	***1***	***6***	***–5***
89	0	0	0
91	***2***	***5***	***–3***
92	***5***	***9***	***–4***
94	1	1	0

There is a distinct difference, however, when we look at the average number of non–Infantry candidates starting RASP1 (Figure 16). The optimal solution shows higher recommended starting numbers than historic averages for eight of the 16 remaining MOSs (11C, 13, 35, 42, 74, 88, 91, 92). Candidates with these MOSs are some of the most difficult to recruit and select (Lasseter 2016). The lower starting numbers for non–Infantry candidates allow higher number of 11Bs to fit within the class capacity constraint. This would not be possible if there were a larger pool of non–Infantry candidates willing to attend RASP1.

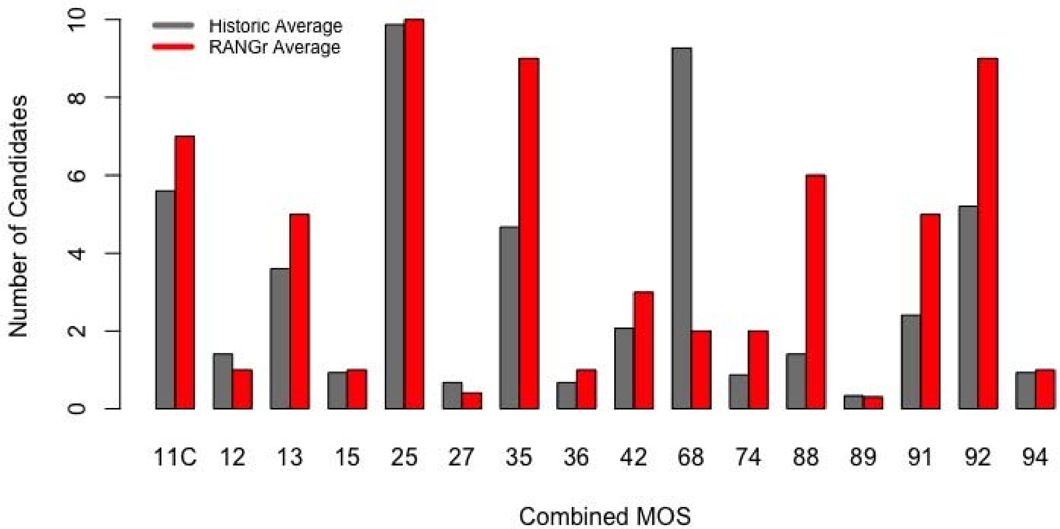

Figure 15. Combined MOS per Class Historic Averages versus RANGr Base Model Averages (without 11B)

2. Changing Demand

We change the demands in this scenario to see effects on class compositions (Figure 16). We use the base case constraints again, but increase the overall demand for each MOS, grade, class, and unit. We analyze the model in ten percent increments up to 30 percent to account for possible under–estimation in the original demand calculation from the MTOE data. If there are changes to the MTOE or unforeseen losses, we can easily adapt RANGr to more specific changes in demand by MOS and grade.

RANGr produces an optimal solution for all demand increases with minimal backlog across all grades and MOSs. When we increase demand by ten percent, RANGr's optimal solution fills all of the demand by the end of the tenth RASP1 class. When we increase demand by 20 percent, RANGr's optimal solution fills 98 percent of the demand by the end of the tenth RASP1 class. RANGr fills 92 percent of the aggregate demand when we increase the original demand by 30 percent. If we increase the barracks capacity to 370 and class capacity to 200, RANGr prescribes a solution that fills all demand even at the 30 percent increase level.

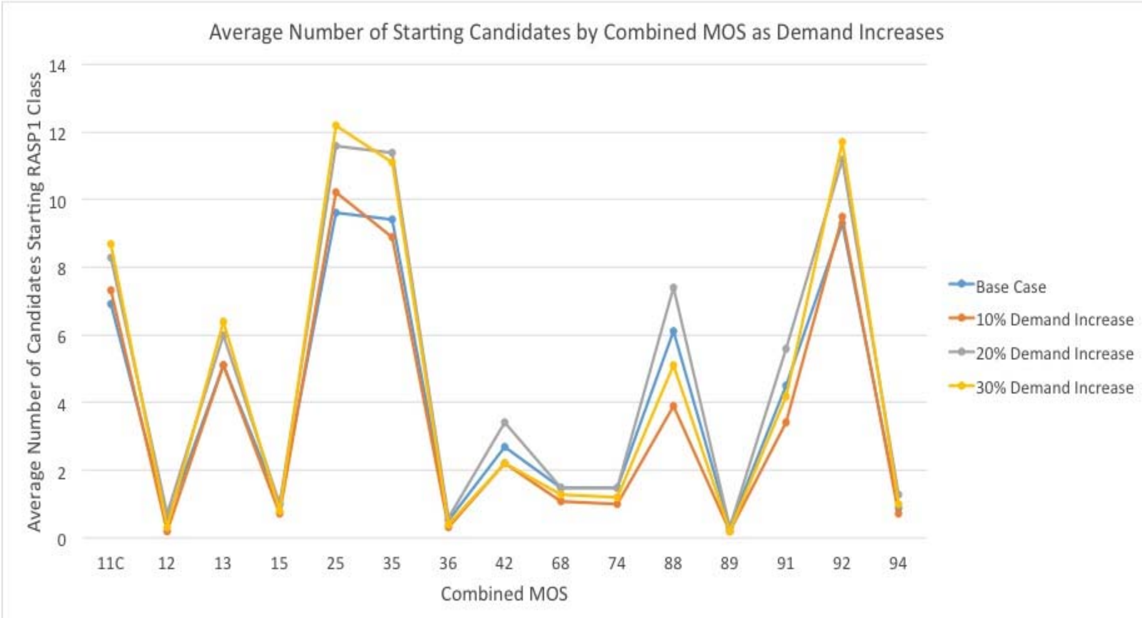

Figure 16. Effects on Class Composition when Increasing Demand

Despite a linear increase to the overall demand, RANGr's optimal solutions are not linear and fluctuate between different demand increases. The prescribed starting numbers for 42, 74, 88, and 91 series MOSs are lower than the base case at the ten and 30 percent demand increase, but higher at the 20 percent demand increase. These MOSs have low graduation rates and RANGr is putting fewer of them in each class as we near capacity constraints. This highlights how RANGr optimizes the RASP1 class composition as parameters and constraints change.

3. Changing Graduation Rates

We change the graduation rates in this scenario to see effects on class compositions. We use the base case constraints again, but decrease the overall graduation rates for each MOS and grade. We analyze the model in five percent increments down to 85 percent of the original rate. This scenario replicates the possibility of a decline in historical graduation rate averages. Also, this allows us to study a lower range of graduation rates without using confidence intervals that in most cases are too wide because of small samples.

RANGr produces an optimal solution and still shows that the Ranger Regiment is able to fill all demands under the current capacity constraints. The differences are not as significant as with the changes in demand, but there is still fluctuation in RANGr's optimal solution (Figure 17).

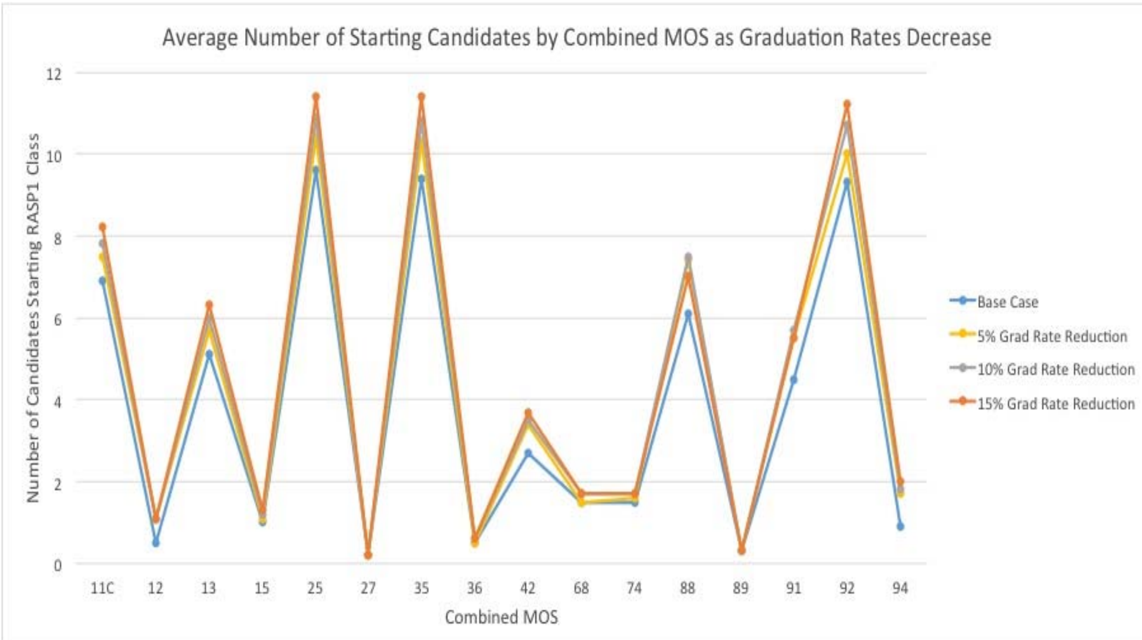

Figure 17. Effects of Decreasing Graduation Rates

4. A Worst-Case Scenario

In a worst-case scenario, we assume demand across all MOSs and grades increases by 30 percent, while the graduation rates across all MOSs and grades decreases to 85 percent of the original values. Because RANGr is trying to minimize the penalties for not filling demand and producing inventory, it attempts to fill the MOSs and grades with the highest graduation rates first. Therefore, the MOSs and grades with the lowest graduation rates typically have the largest backlogs throughout the ten–class time horizon. Ideally, the backlog would be zero for every MOS in every grade for each class. Figure 18 shows the backlog for seven MOSs in the grade of E3 and how every MOS has a backlog starting at class two. After class five, the backlog for 11Bs increases

significantly and by the end of the ten classes, there is a backlog of 37 graduates. This is expected due to the higher demand compared to the other MOSs.

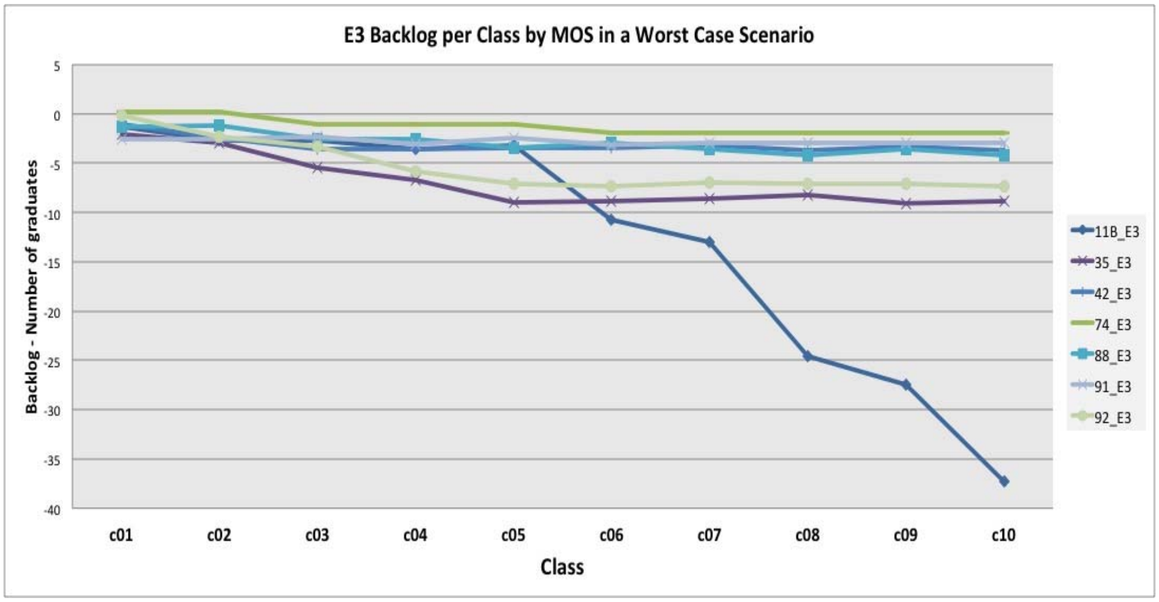

Figure 18. A Worst Case Scenario Backlog for E3s

Despite the backlogs, RANGr is still effective in providing the optimal numbers of candidates to start each RASP1 class under current constraints. This is extremely beneficial because it is difficult to rapidly add capacity. Planners can leverage RANGr to help forecast and justify requirements for increasing or decreasing capacity.

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VI. CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the conclusions from the data analysis and RANGr. It also provides recommendations for follow–on work.

A. CONCLUSIONS

1. Data Analysis

We focus our data analysis on using historic RASP1 candidate data to calculate precise inputs to RANGr. We also use the factors known prior to a candidate's arrival to determine which variables contribute to a candidate successfully completing RASP1.

a. Graduation Rates

Actual graduation rates are lower when including the Transition Platoon data. Many candidates quit upon arrival, before starting a RASP1 class and go directly to the Transition Platoon. This must be a consideration when determining the number of candidates to bring to each RASP1 class. Using only the candidates who start a RASP1 class to estimate graduation rates will cause an under–estimation and could result in unfilled billets and inefficient use of bonuses.

Candidates who have previously recycled have lower graduation rates than non–recycled candidates. The average decrease in graduation rate for 11Bs is 22 percent, and the decrease for non–Infantry MOSs is 12 percent. This is counterintuitive because we assume that learning takes place during the candidate's first RASP1 attempt. The data shows there is no advantage to recycle.

b. Prediction Models

We use a simple logistic regression and partition tree to identify significant factors and help predict success at RASP1. Both models show that RANK, GT_SCORE, POV and Region South help predict success at RASP1. Higher rank (SPC and SGT) increases the probability of graduating from RASP1. Having a POV at RASP1 is also associated with an increased probability of graduating but is likely coincidental and

correlated to other factors (higher rank, age, prior service). Enlisting from a state in the Southern region of the US is negatively associated with the probability of graduating RASP1.

GT Score is the only factor currently collected by the RSTC that may assist in discriminating between candidates prior to their arrival. We show there is evidence that the higher a candidate's GT Score, the higher the probability he will graduate. We also determine that there is not enough evidence to claim there is seasonality in the graduation rates.

2. RANGr

RANGr takes precise estimates of graduation rates using historical RASP1 data and provides optimal solutions to fill demand across the Ranger Regiment. We show that under the current capacity constraints and demand assumptions, it is possible to reduce the number of classes from ten to eight. If reducing the number of classes is not an option, it is still possible to reduce the class sizes from 165 to 121 (with the right composition) and fulfill demand requirements. This reduces the number of candidates by 440 for each FY and could reduce the number of RASP1 cadre required to run the course.

RANGr gives the Ranger Regiment leaders precise numbers of candidates to bring to each RASP1 class. We can easily manipulate parameters to help plan for MTOE changes or unexpected demand fluctuations. We show optimal solutions for universal increases to demand as well as universal decreases in graduation rates. RANGr takes less than ten minutes to run, in most cases, and provides valuable insight to the Ranger Regiment leadership regarding their most precious asset, the young Ranger.

B. RECOMMENDATIONS FOR FUTURE WORK

1. Data Collection Methods and Parameter Estimates

The data collection technique during FY15 and FY16 is ineffective for performing statistical analysis. However, since this thesis began, the leadership of RSTC collects the data using a database instead of Excel workbooks (Burkey 2017). This should make future studies in this area much more user–friendly and require significantly less

wrangling. Also, we recommend avoiding free text in cells unless necessary to describe a special circumstance. To help with prediction models in the future, we recommend collecting the additional data in Table 14.

Table 14. Recommended Data to Capture

Factor	Explanation
Peer Evaluation	Rankings from all other squad members
Contract Type	Type of contract
Prior Service	Binary (1 – Yes, 0 – No)
Reason For Drop	Categorical based on type of drop
Week Dropped	Number 1 to 8
Education	Categorical based on level of civilian education completed prior to RASP1

The estimates we use for demand are not specific to MOS or grade and assume that the attrition rate is equal across all units. This is simplified, but by using other human resource tools we can easily adjust the demand with more timely and accurate numbers.

2. Recruiting Efforts

Information from this data analysis and optimization may support recruiting efforts. Future work may strengthen arguments to incentivize volunteering for MOSs that are historically difficult to fill or have low graduation rates. By capturing the type of contract as a data point, we can determine if it is statistically significant in predicting success at RASP1. We can identify possible trends within the contract types to see if there is a systemic issue with recruiting contracts and incentives.

3. Recommendation to Fill Non–infantry Billets

Based on the FY15 and FY16 data, there is no shortage of 11B candidates and graduates. Bringing non–Infantry candidates to RASP1 and getting them through the same course as an infantryman will always be difficult. There may be an opportunity to

offer certain 11Bs that complete RASP1 incentives to switch into an MOS that is under strength in the Ranger Regiment immediately following graduation. RSTC leadership could develop an order of merit list for graduates in over strength MOSs and make a cut line at a designated threshold. Graduates would have a choice of switching their MOS to serve in the Ranger Regiment or going to a conventional unit as a RASP1 graduate with the potential to reapply after a certain period of time. If a candidate were to decline to switch MOSs and choose to go to the conventional Army, he would be well trained and would still have "RASP1 graduate" on his Enlisted Record Brief.

4. Identifying Factors that Contribute to Success or Failure after RASP1

The Ranger Regiment has some of the greatest leaders in the Army within its ranks. There are also members of the Ranger Regiment who are removed from the unit for failing to meet specified standards. It may be possible to take samples of data from both populations to identify what factors contribute to their success or failure. Ideally, we would trace the factors back as far as possible to identify success or failure early in a Ranger's career to help leaders make critical manning decisions. This information would allow leaders to start grooming exceptional Rangers earlier for positions of greater responsibility. It also could identify Rangers that may need more attention and development to ensure they can meet the specified standards.

APPENDIX A

Table 1. List of all Factors in RASP1 Class Data Set

FACTOR	DESCRIPTION
NAME	Generic ID to protect PII
MOS	one of 44 Military Occupational Specialty
RANK	one of 5 ranks
AGE	Candidate Age in Years at start of RASP1
RGR_HISTORY_TEST	Ranger History test score out of 100
RGR_HIST_RETEST	Ranger History Retest score out of 100
RGR_STANDs_TEST	Ranger Standards Test score out of 100
RGR_STANDARDS_RETEST	Ranger Standards Retest score out of 100
RFR_TEST	Ranger First Responder score out of 100
APFT_DIAG	Diagnostic Army Physical Fitness Test out of 300
APFT_RECORD	Recorded Army Physical Fitness Test out of 300
5MILE_DIAG	Diagnostic 5 mile run in minutes:seconds
5MILE_DIAG2	2nd Diagnostic 5 mile run in minutes:seconds
5MILE_REC	Recorded 5 mile run in minutes:seconds
7MILE_RUCK	7 Mile Ruck March time in minutes:seconds
8MILE_RUCK	8 Mile Ruck March time in minutes:seconds
10MILE_RUCK	10 Mile Ruck March time in minutes:seconds
12MILE_RUCK	12 Mile Ruck March time in minutes:seconds
LANDNAV_TOT_PTs	Total points found on Land Navigation course
RPAT	Ranger Physical Assessment Test in minutes:seconds
PUSHUP1	Number of Pushups on APFT 1
PU1POINTS	Points for Pushups on APFT 1 out of 100
SITUP1	Number of Situps on APFT 1
SU1POINTS	Points for Situps on APFT 1 out of 100
RUN1	2 Mile Run time in minutes:seconds on APFT 1
RUN1POINTS	2 Mile Run score out of 100 on APFT 1
PULLUP1	Number of Pullups on APFT 1
APFT1TOTAL	Total Score on APFT 1 out of 300
PUSHUP2	Number of Pushups on APFT 2
PU2POINTS	Points for Pushups on APFT 2 out of 100
SITUP2	Number of Situps on APFT 2
SU2POINTS	Points for Situps on APFT 2 out of 100
RUN2	2 Mile Run time in minutes:seconds on APFT 2

FACTOR	DESCRIPTION
RUN2POINTS	2 Mile Run score out of 100 on APFT 2
PULLUP2	Number of Pullups on APFT 2
APFT2TOTAL	Total Score on APFT 2 out of 300
PUSHUP3	Number of Pushups on APFT 3
PU3POINTS	Points for Pushups on APFT 3 out of 100
SITUP3	Number of Situps on APFT 3
SITUP3POINTS	Points for Situps on APFT 3 out of 100
RUN3	2 Mile Run time in minutes:seconds on APFT 3
RUN3POINTS	2 Mile Run score out of 100 on APFT 3
PULLUP3	Number of Pullups on APFT 3
APFT3POINTS	Total Score on APFT 3 out of 300
DOB	Date of Birth M/D/Y
ARRIVAL_DATE	Date arrived to RSTC for RASP1 M/D/Y
BASD	Basic Active Service Date M/D/Y
PRIOR_SERV	Binary 1–Prior Service, 0–Initial Entry
Contract	Type Of Contract
GT_SCORE	General Technical Score 0 to 150
HWI	Binary 1 – Prior Hot Weather Injury, 0 – Not prior HWI
CWI	Binary 1 – Prior Cold Weather Injury, 0 – Not prior CWI
RECYCLE	Binary 1 – Previously Recycled, 0 – Never Recycled
POV	Binary 1 – Has Privately Owned Vehicle at RASP1, 0 – No POV at RASP1
CLASS	RASP1 Class Number FY_ClassNumber
ABN	Binary 1 – Airborne Qualified, 0 – Non Airborne Qualified
MARRIED	Binary 1 – Married, 0 – Not Married
CURRENT_ASSIGNMENT	Current Unit
HOR	Service Members Home of Record
HORState	Service Members Home of Record State
GLASSES	Binary 1 – Wears Glasses, 0 – Does Not Wear Glasses
FINANCE_ISSUES	Binary 1 – Issues with Finance, 0 – No issues with Finance
INSTRUCTOR COMMENTS	Free Text by NCOIC with various comments on performance/issues
Region	One of four Regions for Service Members Home of Record State

APPENDIX B

Table 2. Base Case Demand for RANGr

GRADE / MOS	E3	E4	E5	Total	Average/Class
11B	131	211	11	353	35.3
11C	20	10	0	30	3.0
12	1	1	2	4	0.4
13	10	10	0	20	2.0
15	2	2	0	4	0.4
25	14	26	0	40	4.0
27	0	1	0	1	0.1
35	15	18	1	34	3.4
36	0	2	1	3	0.3
42	5	4	0	9	0.9
68	3	2	2	7	0.7
74	2	3	2	7	0.7
88	6	6	1	13	1.3
89	0	0	2	2	0.2
91	4	10	2	16	1.6
92	12	25	2	39	3.9
94	1	4	1	6	0.6

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